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ANALYZING THE PERFORMANCE OF PURE LATERATION IN INDOOR ENVIRONMENTS WITH VARIOUS PERFORMANCE METRICS

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ABSTRACT. Nowadays, determining the location of the users and devices in indoor buildings is promising research topic. Accurate position determination of the users for indoor environments is used for numerous applications such as public safety, supermarkets, health care applications, travelling, social networks and tourism. However, global positioning systems created for outdoor localizations cannot be used for indoor positioning systems (IPS) because detecting the exact position of a target is an issue for IPS. For indoor environments, there are several positioning algorithms such as lateration, fingerprinting, dead reckoning etc. Lateration is low cost and easy to deploy when compared to other existing algorithms. Therefore, in this study, received signal strength based pure lateration that uses synthetic data generated from MATLAB is proposed. The performance of pure lateration is investigated in terms of several performance metrics such as effect of varying number of the access points (AP), varying dimensions of the measurement area, varying Gaussian Noise power and varying number of test points in the field. The simulation of the pure lateration algorithm is conducted in MATLAB. The effect of the performance metrics are investigated and discussed in details. According to the results, accuracy performance of lateration is increased when the number of APs increase in the area, however this will bring some hardware costs. In addition, when the number of test points increases in the field, in other words the step size between two test points decreases in the field the error performance of lateration is also enhanced however, this will also cause to computational costs. Finally, enlarging the measurement area causes to decrease the accuracy performance of lateration as expected. The main purpose of this study is to obtain the optimum conditions for lateration to provide a solution for real time applications. For future work, the real time implementations of this study are performed and to improve the accuracy performance, it is aimed to use a curve fitting idea to the measured values.

Keyword and phrases. Pure lateration, indoor positioning, triangulation, GPS.
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1. Introduction

Recent years, the determination of location of a device has become an important requirement in numerous applications. Global Positioning System (GPS) has become fully useful in 1995. The GPS is a space-based satellite navigation system that provides position and time information in all conditions, anywhere where there is an unobstructed line of sight to three or more GPS satellites [1]. The GPS includes tri-angulation technique to detect physical positions of the users in outdoor environments. On the other hand it is not useful for exact determination of the locations of the users in indoor environments [2]. The concrete walls cause to attenuation of the signals transmitted from satellites and thus the signals do not penetrate walls. Thus, finding the location of a target in a building becomes unfeasible.

In recent years, according to the enhancements in the technologies, people pass the time of day in indoor environments therefore the demand for indoor positioning technologies arises. In these indoor buildings, people can use IPS to arrive gate in an airport, patient services in hospitals or products in supermarkets. With prospering actualizations of the IPSs, a variety of applications can be realized for indoor places [3]. To illustrate, safety, social network and health care applications can be performed by using IPS. In addition, as instance, indoor localization technique can also ensure innovative and accurate ways to find out the position of a person in a building in the event of a disaster because person’ s life matter, gaining some time during this kind of an event, is so critical [4].

Latterly, IPS becomes a popular research field because of the above mentioned implementations thus many research and publications have been made in IPS field. Various IPS studies are proposed by authors [5]. In a Received Signal Strength (RSS)-based localization system [6] the position of a target can be found by calculating the distance of an object from the transmitter using tri-angulation or tri-lateration approaches.

The well-known approaches using for signal measurements are: Angle of Arrival (AOA), Time of Arrival (TOA), Time Difference of Arrival (TDOA) and Received Signal Strength Indicator (RSSI) [3]. AOA [7] needs computation of the angles at which the signals arrive from the un-located device to the anchor nodes. This scheme only requires two measuring units for 2D-positioning and it does not require synchronization between the measurement units. AOA can be utilized ably when LOS appears but the accuracy diminishes in multi-path environments. TOA utilizes the distances between the transmitting nodes and the receiving nodes from the transmission time delays and the corresponding speed of the signals to find out the positions of the objects [8, 9]. TOA ensures high precision, however, it causes to extra cost because of the high hardware complexities. TDOA technique also uses distance-based measurements to determine the positions of the objects [10]. They find the relative locations of the transmitters based on the variation of the TOA of the propagation of the signals in the transmitters and multi-sensors. When the signal reaches to two reference points, the difference in arrival time can be used to calculate the differences of the distances between the object and the two reference points. It is less complicated than TOA and it fulfils notable certainty performances.

Value of a RSSI is the measure of the power level of RSS. It is measured by decibel-milliwatt (dBm) that corresponds to a negative number. If the received signal reaches strong the value becomes closer to zero. To find out the position of an object with RSSI, the RSSI values between the sensors attached to a target user and enclosing access points (APs) with pre-defined positions should be measured [11]. The combinations of these multiple RSSI values can be utilized to compute the approximate location of the target. Frequently, at a minimum 3 APs are needed to find out the location of a target. The positions of the targets are acquired by calculating the distances of the objects from senders by the help of tri-angulation or tri-lateration techniques. RSSI based localization is easy to use by comparison with the techniques that use AOA and TDOA [12]. For RSSI methods, particular equipment both at the cell-phones and the wireless interface cards are not needed to be utilized [13].

2. Pure Lateration Technique

Location detection by the help of distance measurements using signal strengths is named as lateration. This scheme is used in IPS due to its preciseness and cheapness. The lateration techniques are based on position information of the reference points and the distances to them.

Firstly, to find the accuracy error of pure lateration, the RSSI Matrix which includes noisy RSSI measurements of APs on each test point in a room can be defined as shown below:

$$X_{RSSI} = \begin{bmatrix} RSSI_{(1,1)} & \cdots & RSSI_{(1,T)} \\ \vdots & \ddots & \vdots \\ RSSI_{(K,1)} & \cdots & RSSI_{(K,T)} \end{bmatrix} \quad (1)$$

Here, T corresponds to number of test points in the measurement area and N denotes the number of APs in the field. As instance, T can be 196 and K can be 4. The distance of an object from the transmitter can be computed by using (2) given below, after measuring the received power at the target position given that A and n values are known:

$$r_P = 10^{\frac{A-X_{RSSI}(x,y)}{10n}} \tag{2}$$

In here, A value shows the power of an AP in dBm and n corresponds to the path loss exponent of the environment. By using rP values and following two equations, Eq. (5) can be obtained:

$$C_{act} = \begin{bmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) \\ \vdots & \vdots \\ 2(x_K - x_1) & 2(y_K - x_1) \end{bmatrix} \tag{3}$$

$$D = \begin{bmatrix} r_{p1}^2 - r_{p2}^2 + x_2^2 + y_2^2 - x_1^2 - y_1^2 \\ \vdots \\ r_{p1}^2 - r_K^2 + x_K^2 + y_K^2 - x_1^2 - y_1^2 \end{bmatrix} \tag{4}$$

$$\begin{bmatrix} x_{est} \\ y_{est} \end{bmatrix} = (C_{act}^T C)^{-1} C_{act}^T D \tag{5}$$

Eq. (5) shows the estimated locations of the pure lateration method. To find the estimated error in each test point, the difference between estimated locations and actual locations can be used as shown in (6):

$$e = \begin{bmatrix} x_{est} \\ y_{est} \end{bmatrix} - \begin{bmatrix} x \\ y \end{bmatrix} \tag{6}$$

3. Results

Simulations and analyses of pure lateration are conducted in MATLAB. The results of simulations and discussions are presented in this section. Varying number of access points (APs), varying step sizes and Gaussian Noise parameters are used to obtain several simulation results.

Fig. 1 illustrates the error value of each test point of pure lateration under low Gaussian Noise (standard deviation of noise is 2). Here, there are 196 test points and 4 APs which are located at the corners of measurement field. The dimensions of the field are 6m x 6m. From this figure, it is obtained that lateration error increases especially when the test points are very close to the APs. The whole distribution of the lateration error on each point can be obtained from this figure. Note that, in here the average lateration error is approximately 1.3321 m.

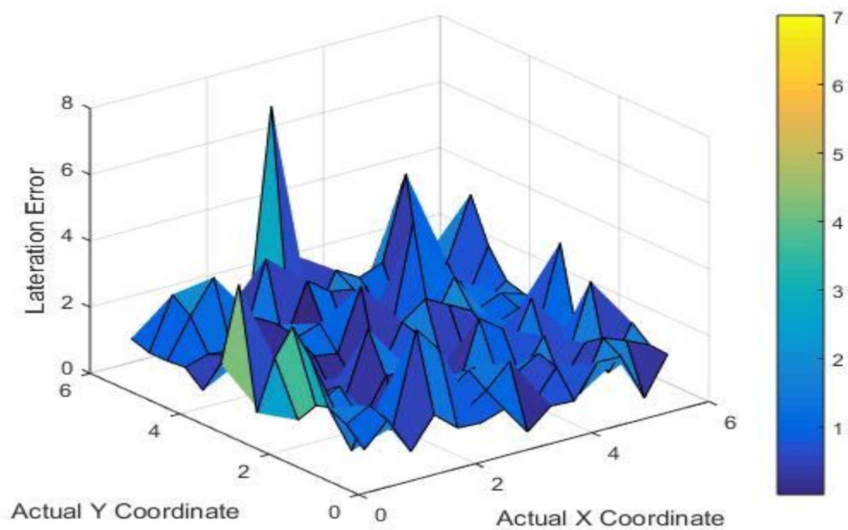

FIGURE 1. Lateration error distribution of each point under low Gaussian Noise

Fig. 2 illustrates the error distribution of each test point of pure lateration under lower Gaussian Noise (standard deviation of noise is 1). Here, there are 196 test points and 4 access points which are located at the corners of measurement field. The dimensions of the field are 6m x 6m. From the figure, it is obtained that lateration error increases especially when the test points are very close to the APs. The whole distribution of the lateration error on each point can be obtained from this figure. Note that, in here the average lateration error is approximately 0.5869 m. The average error is decreased dramatically when the noise is decreased.

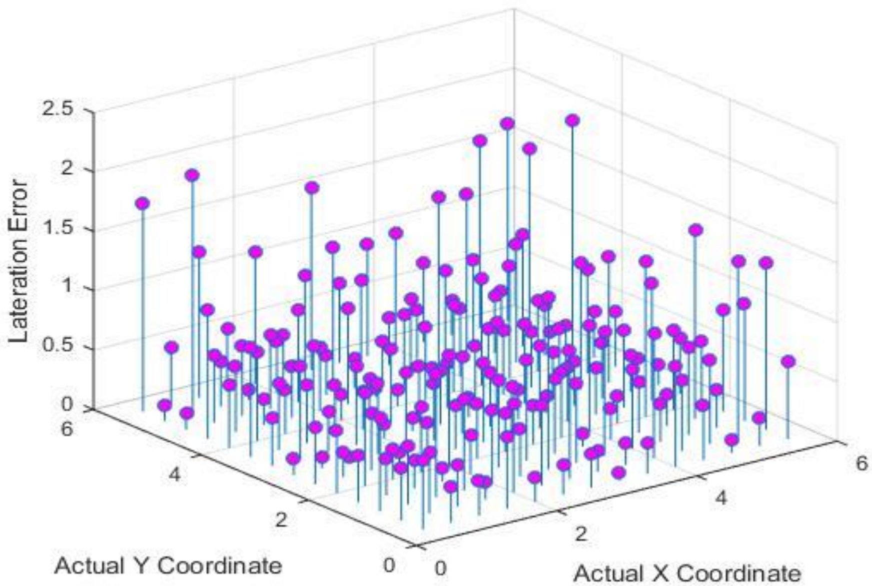

FIGURE 2. Lateration error distribution of each point under lower Gaussian Noise

To investigate the effect of Gaussian Noise on pure lateration, the simulations are conducted for varying Gaussian Noise values. Fig. 3 shows the average error performance of pure lateration in term of varying Gaussian Noise. The average error increases when the noise increases in the system as expected.

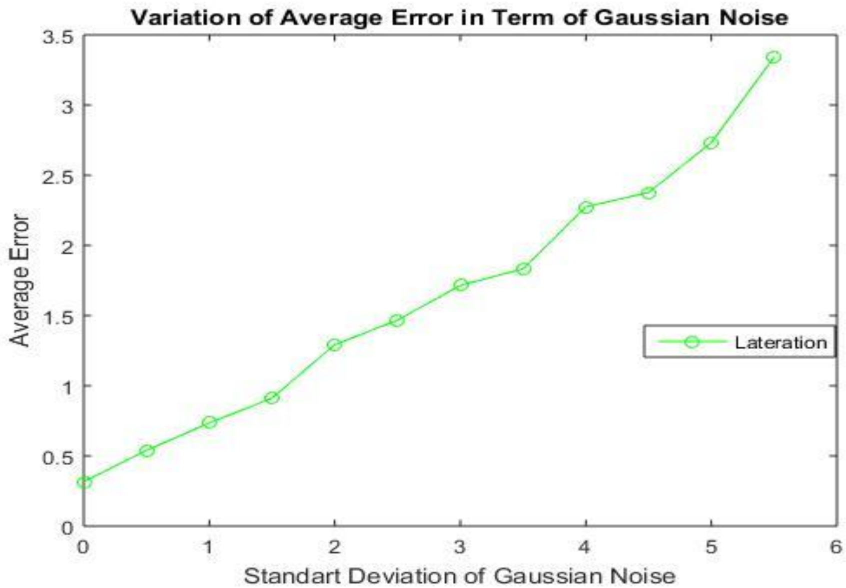

FIGURE 3. Average lateration error according to different noise values

Under low Gaussian Noise (standard deviation of 2), the performance of pure lateration is also investigated in this study. Fig. 4 illustrates the average error value of each iteration of pure lateration under 100 independent iterations. Here, there are again 4 APs, 196 test points in 6m x 6m measurement area. According to the results, the average error performance of lateration varies between 1.2 m and 1.5 m.

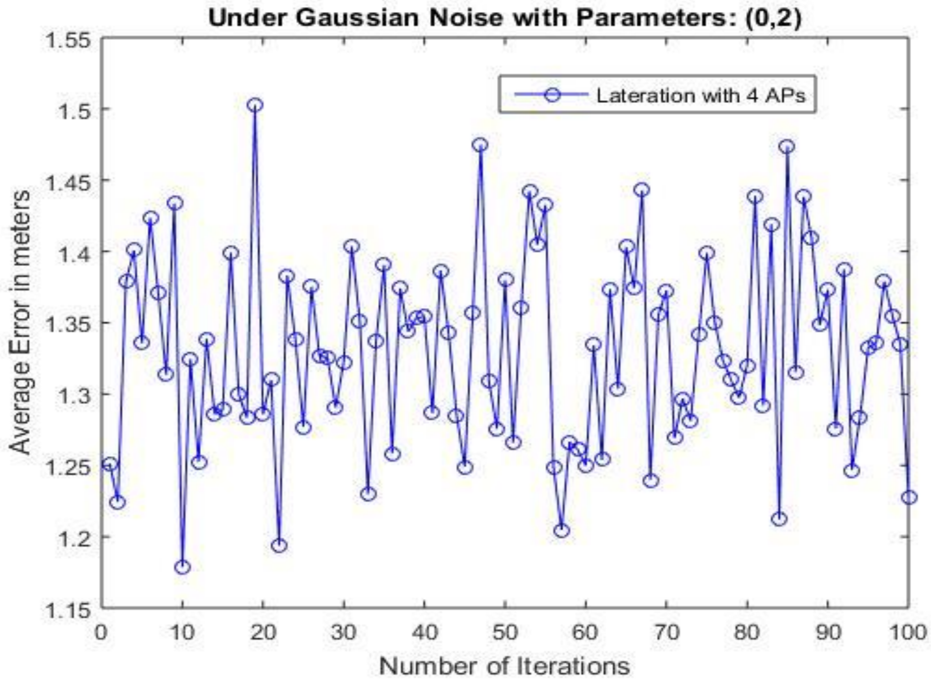

FIGURE 4. Average error performance of lateration with iterations

Table 1 shows the variation of lateration error according to varying number of APs under 100 independent iterations. Here, there are 196 test points and noise parameter is 2 in 6m x 6m field. According to these simulation results, it is obtained that, when the number of APs increase in the measurement area, the error performance of pure lateration enhances. However, increasing the number of APs brings extra computational, hardware and financial costs to the designers and researchers.

TABLE 1. Average lateration errors according to different number of access points

Number of APs	**Average Lateration Error in meters**
3	1.6925
4	1.3182
6	1.2301
8	1.1324

Table 2 shows the variation of lateration error according to different room sizes for 100 independent iterations. Here, there are 196 test points and noise parameter is 2. According to these simulation results, it is obtained that, when the room size (measurement area) is enlarged the accuracy performance of pure lateration decreases as expected. This problem can be solved by using more number of test points in other words using lower step size parameter or increasing the number APs in the field as illustrated in Table 1.

TABLE 2. Average lateration errors according to varying field dimensions

Field Dimensions	**Average Lateration Error in meters**
3m x 3m	0.6001
6m x 6m	1.3257
12 m x 12 m	2.6913
18 m x 18 m	4.0724
24 m x 24 m	5.4321

Table 3 shows the error performance of pure lateration for the parameters: 4 APs and 196 TPs under 100 independent iterations. As expected and discussed above, when the noise increases in the measurement environment, the accuracy performance of pure lateration decreases dramatically.

TABLE 3. Average lateration errors according to varying Gaussian noise

STANDART DEVIATION VALUE OF GAUSSIAN NOISE	AVERAGE LATERATION ERROR IN METERS
0.05	0.0304
0.2	0.1227
0.5	0.3062
1	0.6205
2	1.3229
4	3.3409
5	4.9849

3. Conclusions

Detecting the locations of the users in buildings has been an important research topic recent years. IPS can be utilized a variety of fields such as, shopping applications, social platforms, logistics, tourism sectors and transportation. However, GPS is designed for outdoor places, is not proper for IPS, making certain location determination a extorsive issue for IPS. In this study, pure lateration method that uses existing infrastructure, is proposed. By increasing the number of APs, the pure lateration technique improves the precision of location estimations. The usage of the existing substructure turns the designed method into cheaper when comparing with existing solutions that need pricy components. The proposed method is investigated under different performance metrics in MATLAB. The results of the simulations are evaluated and discussed in details to determine the optimum solution of pure lateration in indoor environments. As a future work, it is planned to use polynomial fitting algorithms to enhance the accuracies of the lateration schemes.

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